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Experiments to Measure Material and Mechanism Damping at Cold Temperatures

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MOTIVATION & OBJECTIVES

- NGST requires nanometer stability of OTE at 40K
- Damping at cryo temperatures expected to be extremely low ...
- But very little data available, especially on materials of interest
- NGST funded the development of a cryogenic damping test facility at JPL.
- The cryogenic damping laboratory provides a <u>unique</u> capability
- Experiment Requirement:
  - Damping accuracy $\zeta > 10^{-3}$ %
  - Minimize external damping sources
  - Temperature > 25 °K
  - NGST representative materials and hardware
  - Correlate to model

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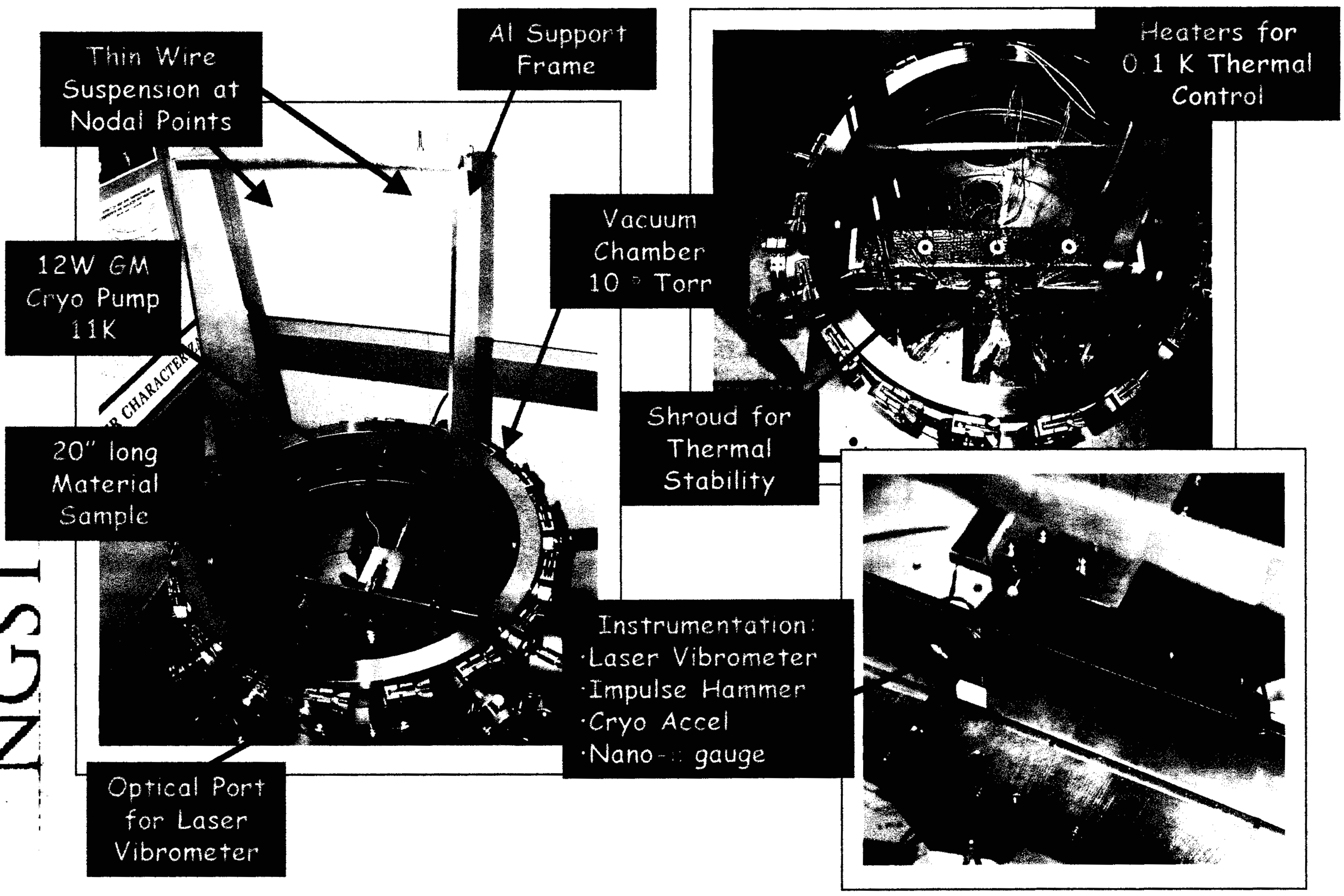
CRYO DAMPING TEST FACILITY



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TYPICAL TEST DATA: Al 6061-T6

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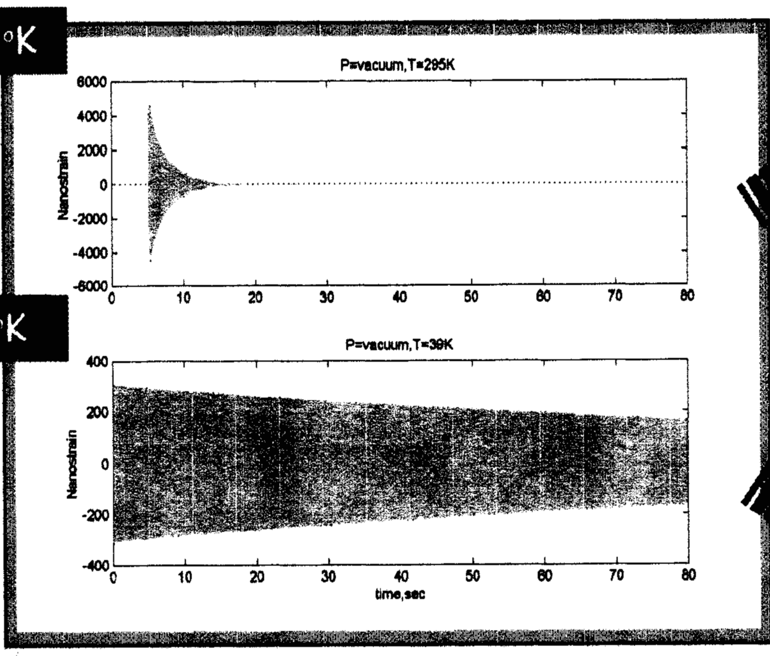
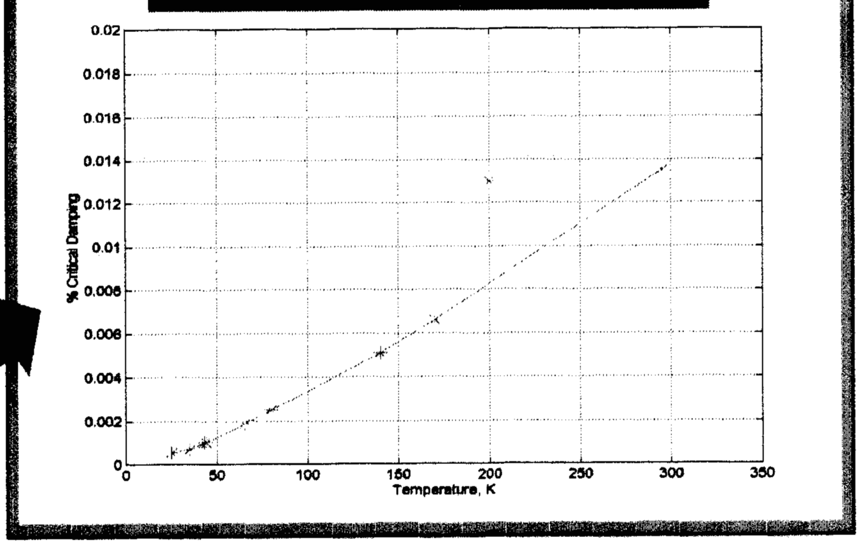
Extract damping through decay rate of the exponential envelope

293 °K

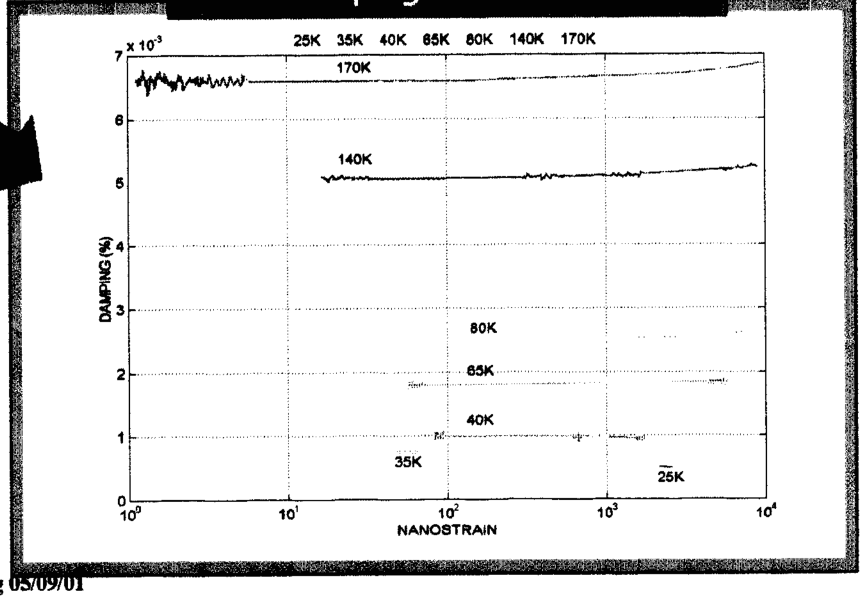
39 °K



Damping vs. Temperature



Damping vs. Strain



For low strains, the damping is independent of strain and dominated by thermoelastic effects

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Zener Damping Model

- Models the thermoelastic energy loss of beams undergoing bending strain
- Applies to homogeneous isotropic metallic materials
- Damping induced by atomic dislocation and heat dissipation
- Damping (linearly) proportional to temperature !!!
- Damping a function of frequency
- Damping not a function of strain (above the relaxation frequency)

$$\xi = \frac{\alpha^2 E T}{2 C_p \rho}\left[\frac{\omega\tau}{1+(\omega\tau)^2}\right]$$

$$\tau = \frac{C_p h^2 \rho}{\kappa \pi^2}$$

α = coeff of thermal expansion
E = modulus of elasticity
T = temperature
C_p = specific heat
ρ = material density
ω = frequency of vibration
τ = thermal relaxation time
h = specimen thickness
κ = thermal conductivity

Caveats

- Zener model does not predict damping for non-metallic materials such as composites
- Zener model does not predict damping from axial or torsional strains.
- System level damping will also be influenced by friction of mechanisms and interfaces.

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Properties of Al 6061-T6 Samples

Specimen	Thickness (mm)	Nominal Frequency at 293K (Hz)	Support Separation (mm)	End Mass (kg)
Al-A	6.267	126	279	0
Al-B	3.142	63	279	0
Al-C	1.510	31.5	279	0
Al-D	1.510	18.2	406	0.1880
Al-Weld	6.291	126	279	0

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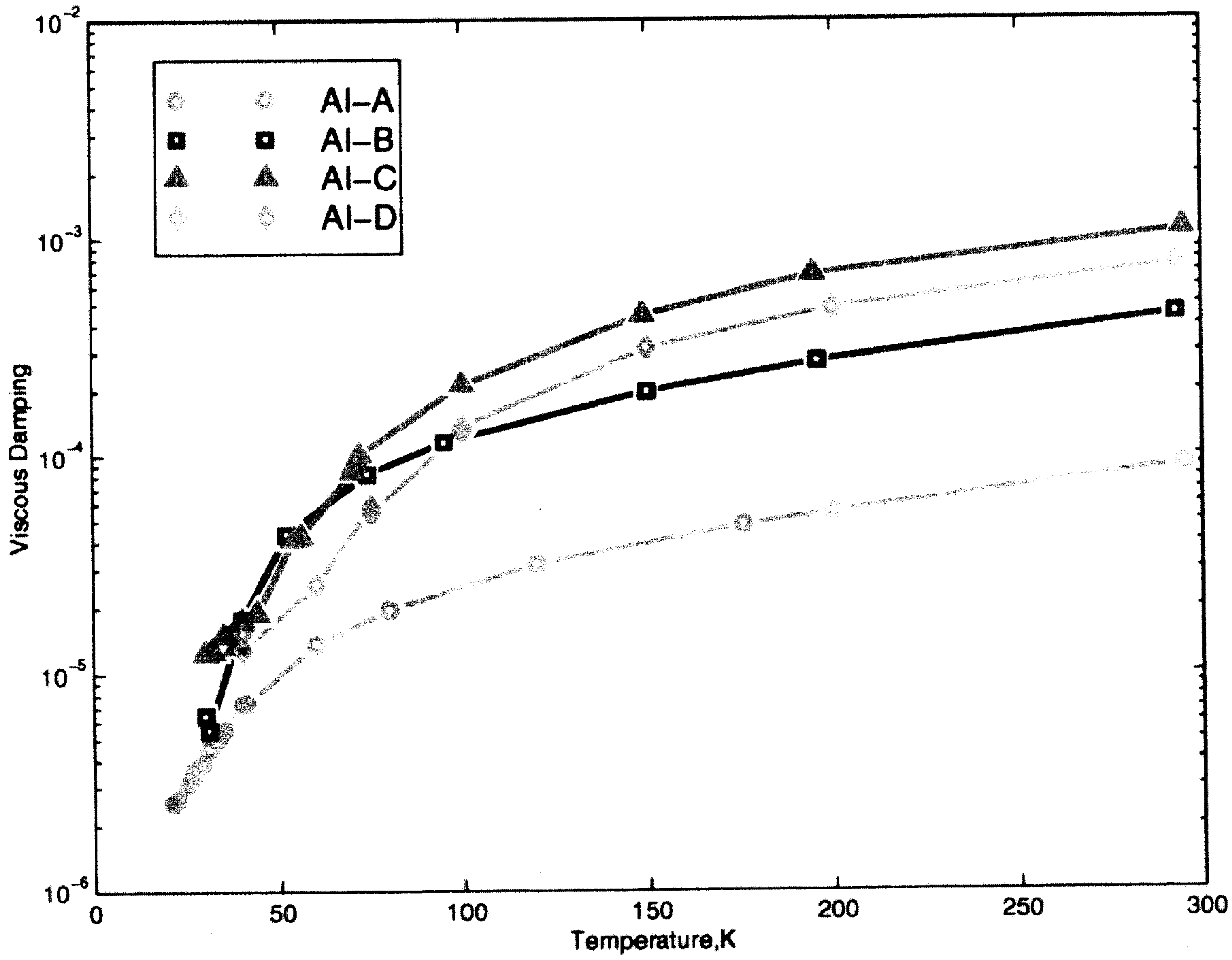
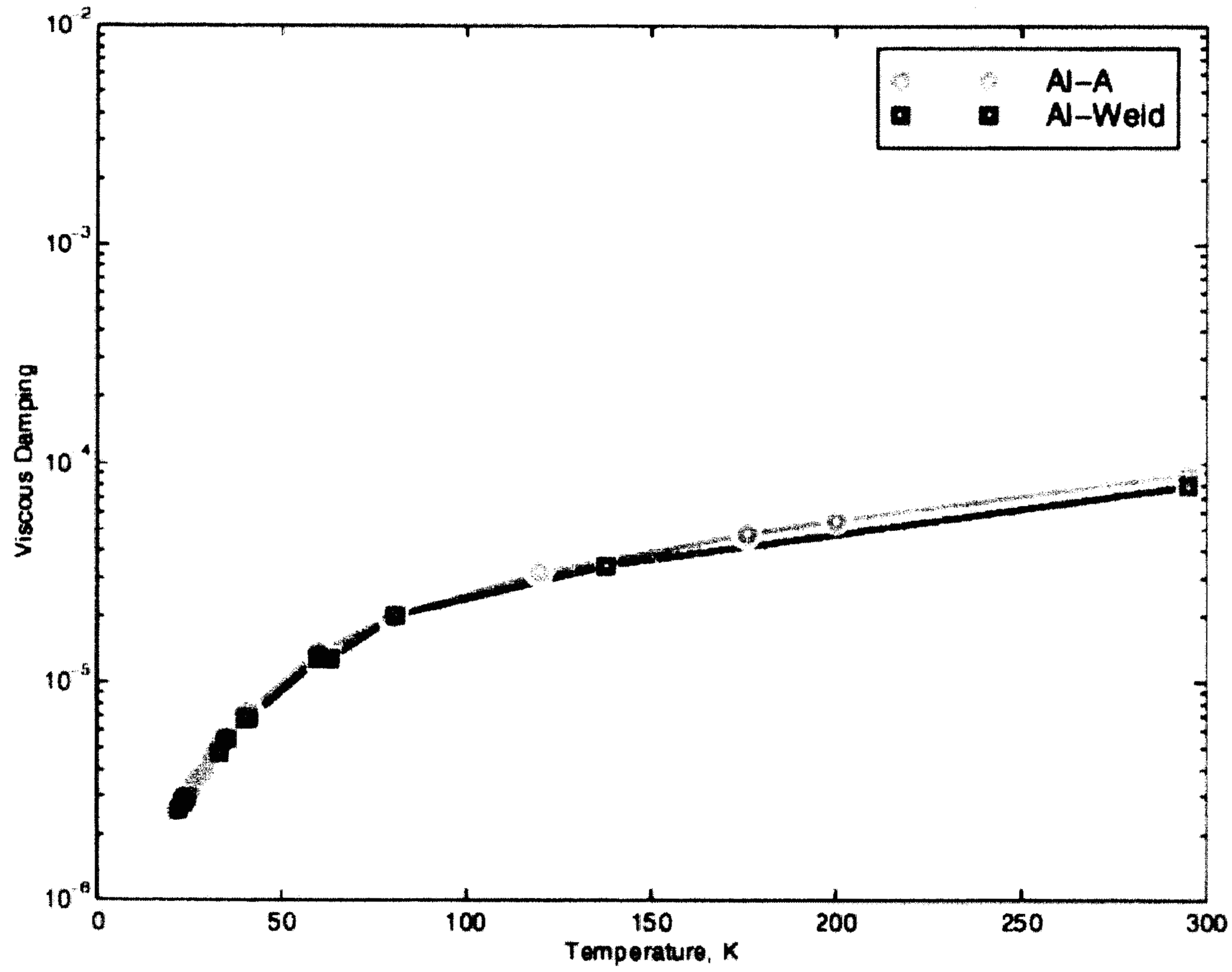
Damping of Al 6061-T6 vs. Frequency and Temperature

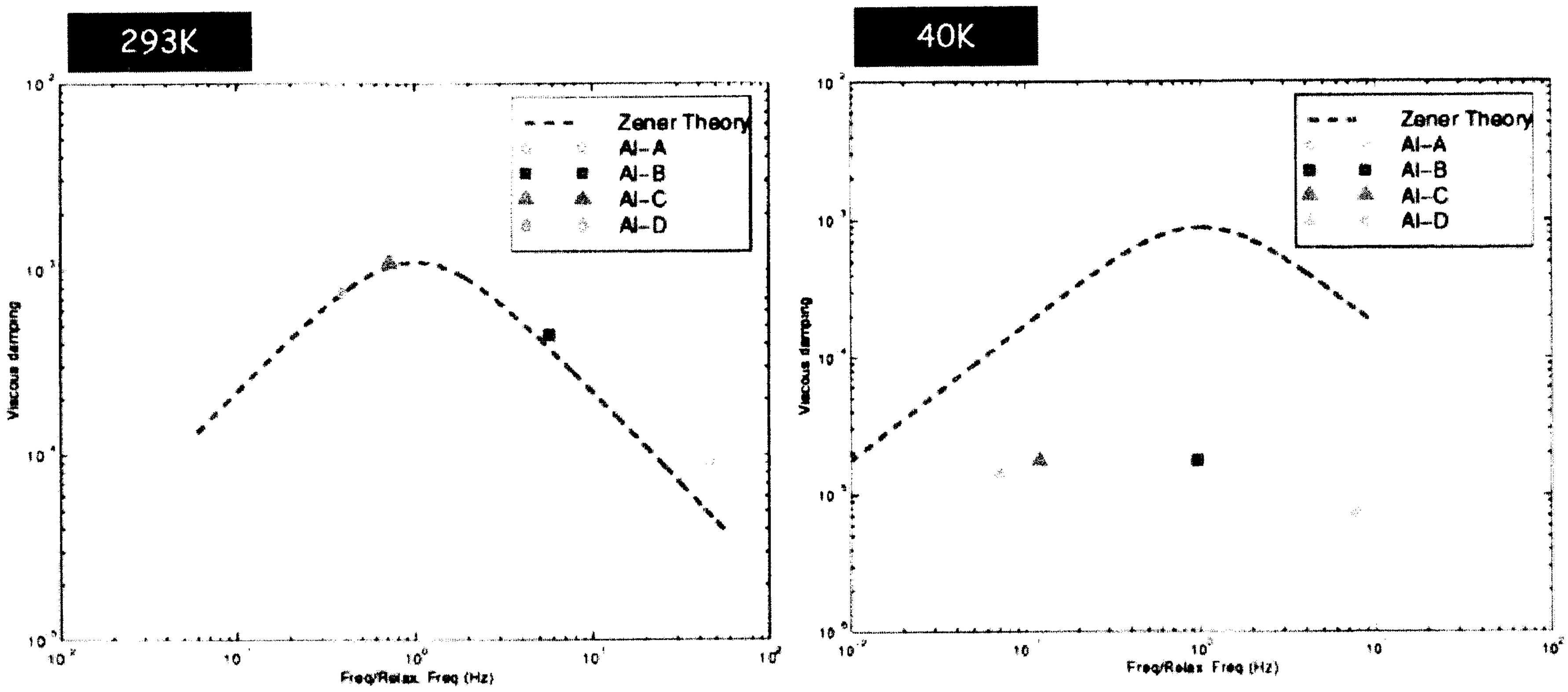


Welded Al 6061-T6 Sample



Welding does not significantly affect damping

Comparison to Zener Model Predictions



- *Zener model predicts room temperature damping*
- *Prediction fails at cryo because of errors in thermal properties or theory*
- *Largest damping change for frequency close to thermal relaxation frequency*

Summary of Measured Damping Values for Aluminum 6061-T6

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Sample	ζ_{293}	ζ_{40}	Ratio ζ_{293}/ζ_{40}
Al-A	9.0e-5	0.74e-5	12.2
Al-B	44.8e-5	1.8e-5	24.9
Al-C	109e-5	1.8e-5	60.6
Al-D	75.5e-5	1.4e-5	53.9
Al-Weld	8.1e-5	0.69e-5	11.7

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- *Largest damping change for frequency close to thermal relaxation frequency*
- *At 40K damping for Al ~1e-3%, and is less sensitive to frequency*

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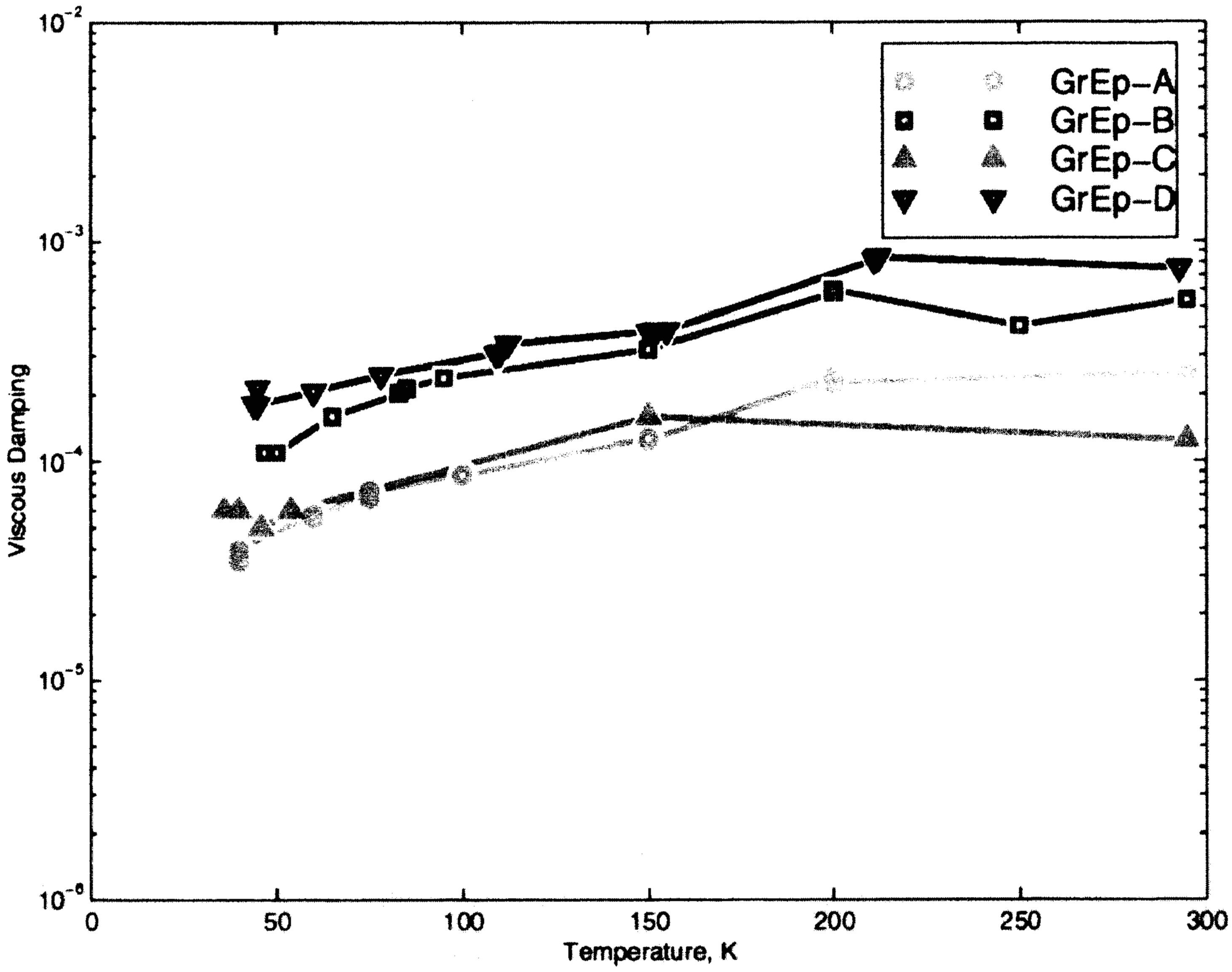
Damping of Various Composites



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Properties of Beryllium Samples

Specimen	Thickness (mm)	Nominal Frequency at 293K (Hz)	Support Separation (mm)	End Mass (kg)
Be-A	6.50	337.2	279	0
Be-B	2.65	137.1	279	0
Be-C	1.40	72.5	279	0
Be-D	1.40	40.8	418	0.064

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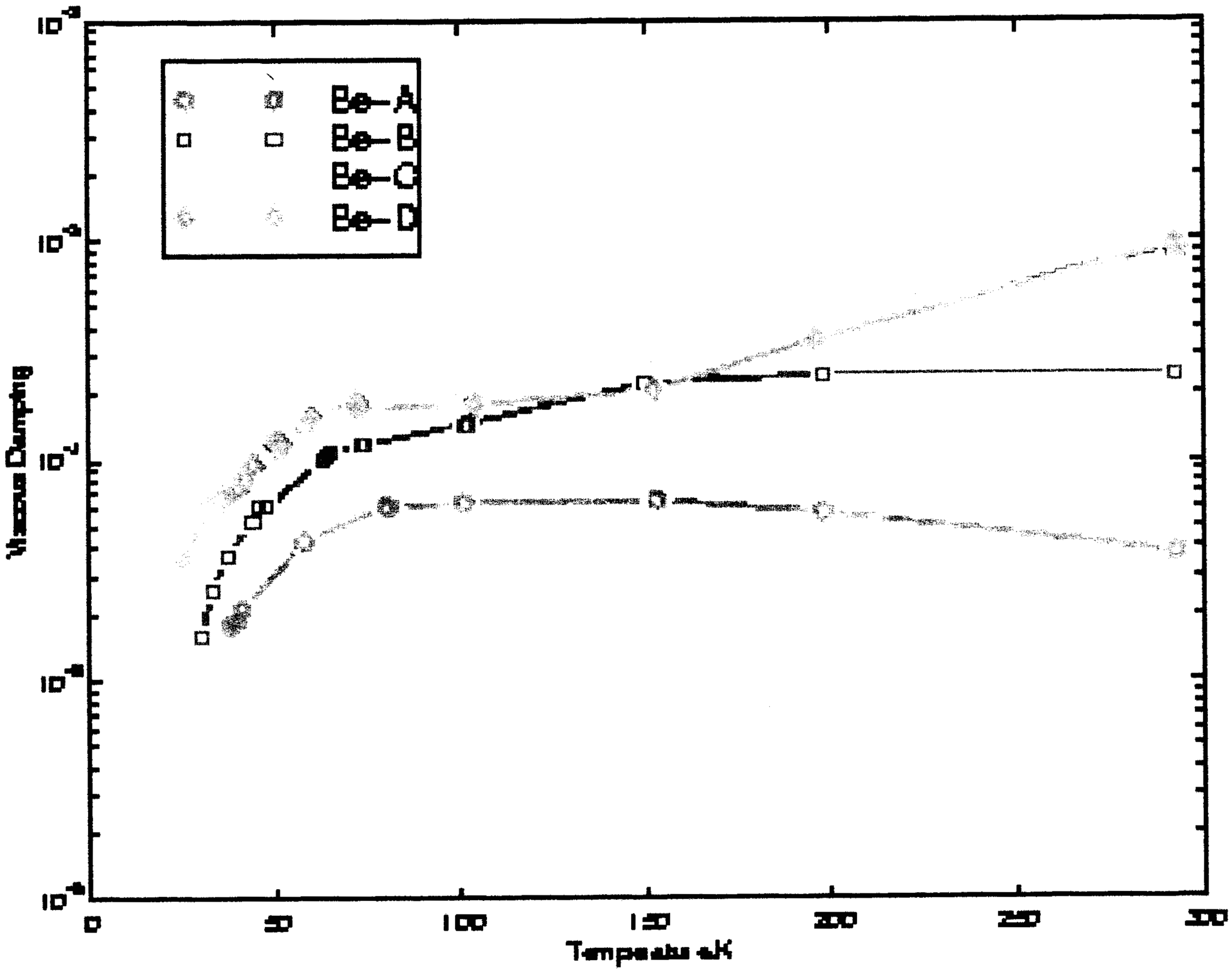
Damping of Beryllium



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M. Levine MSFC - Technology Mtg 05/09/01

Summary of Measured Damping Values for Beryllium

Sample	ζ_{293}	ζ_{40}	Ratio ζ_{293}/ζ_{40}
Be- A	3.8e-5	2e-5	1.9
Be -B	28e-5	4e-5	7
Be -C	88e-5	8e-5	11
Be -D	91e-5	8e-5	11.4

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- *Zener prediction in progress*
- *The ratio between RT and 40K is less than for Al, but τ may be different.*
- *Below 40K Be damping drops off suddenly.*
- *At 40K Be damping is ~5e-3%*

Conclusions

- Developed a unique facility to measure damping at a range of temperatures from RT to 20K.
- More materials are currently being tested including fused silica.
- Other cryo tests:
  - Micro-G Accelerometer calibration in progress
  - Friction devices and actuators will be tested this summer.
  - Second facility is being set up to measure creep and CTE from RT to 30K. Projected accuracy is 0.1ppm.